US005092834A

United States Patent [19]

Bradshaw et al.

[11] **Patent Number: 5,092,834**

[45] **Date of Patent: Mar. 3, 1992**

[54] **APPARATUS AND METHOD FOR THE REMOTE HANDLING OF HIGHLY RADIOACTIVE SOURCES IN THE TREATMENT OF CANCER**

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[21] Appl. No.: **596,928**

[22] Filed: **Oct. 12, 1990**

[51] **Int. Cl.**[5] **A61N 5/00**

[52] **U.S. Cl.** **600/7**; 600/3

[58] **Field of Search** 600/3, 7

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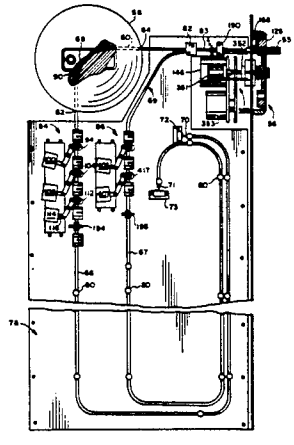
Assistant Examiner—Scott R. Akers
Attorney, Agent, or Firm—Fitch, Even, Tabin & Flannery

[57] **ABSTRACT**

Remote controlled afterloader apparatus and method positions high activity radioactive sources through a catheter within a human body for treatment of cancerous tissue. The afterloader includes an operating console and a remotely located computer controlled wire driver. The wire driver includes active and dummy source wires and channels for the storage of such wires. Stepper motors precisely position the wires in response to computer control and data from wire position encoders. An emergency DC motor retraction system provides a high degree of safety against system malfunction. Timing arrangements are included for timing patient treatment duration and emergency wire retraction time. A turret is provided with safety locking and cross-checking systems to permit use of multiple catheters. Treatment profiles are conducted from the maximum treatment position whereby only tension or retraction forces are used to position the active wire.

2 Claims, 8 Drawing Sheets



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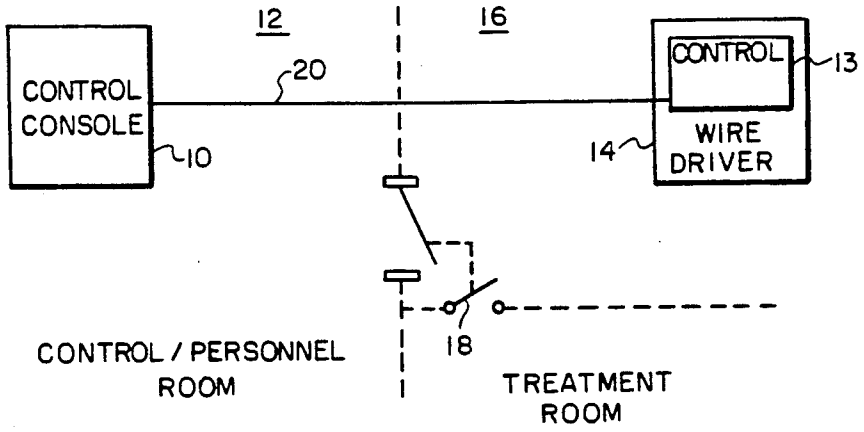

12
16
CONTROL CONSOLE
10
20
CONTROL
13
WIRE DRIVER
14
18
CONTROL / PERSONNEL ROOM
TREATMENT ROOM

FIG. 1

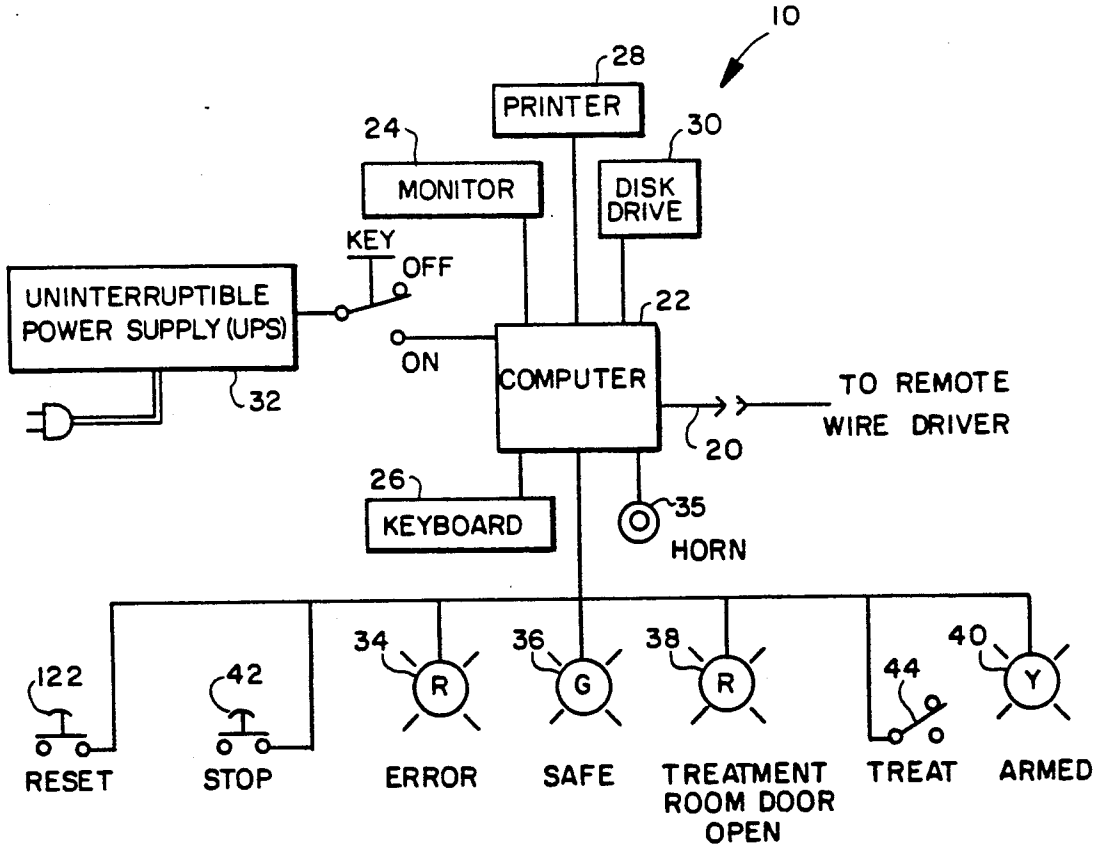

10
28
PRINTER
24
MONITOR
30
DISK DRIVE
KEY
OFF
ON
UNINTERRUPTIBLE POWER SUPPLY (UPS)
32
22
COMPUTER
TO REMOTE WIRE DRIVER
20
26
KEYBOARD
35
HORN
122
RESET
42
STOP
34
R
ERROR
36
G
SAFE
38
R
TREATMENT ROOM DOOR OPEN
44
TREAT
40
Y
ARMED

FIG. 2

FIG. 3

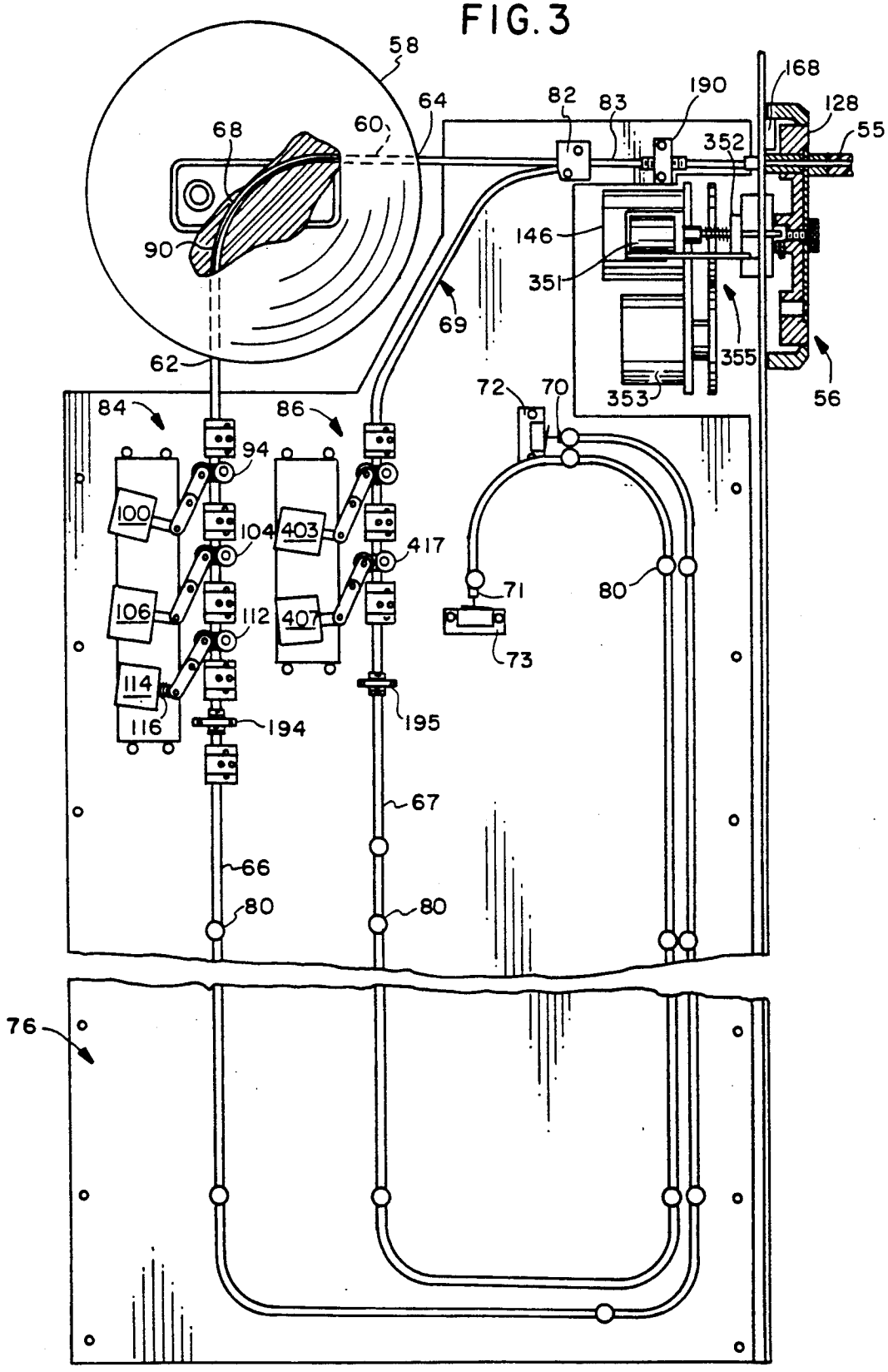

58
64
82
83
190
168
128
55
68
60
352
90
146
351
69
355
62
353
56
72
70
84
86
94
100
104
403
417
106
112
407
71
80
73
114
116
194
195
67
66
80
80
76

FIG. 4

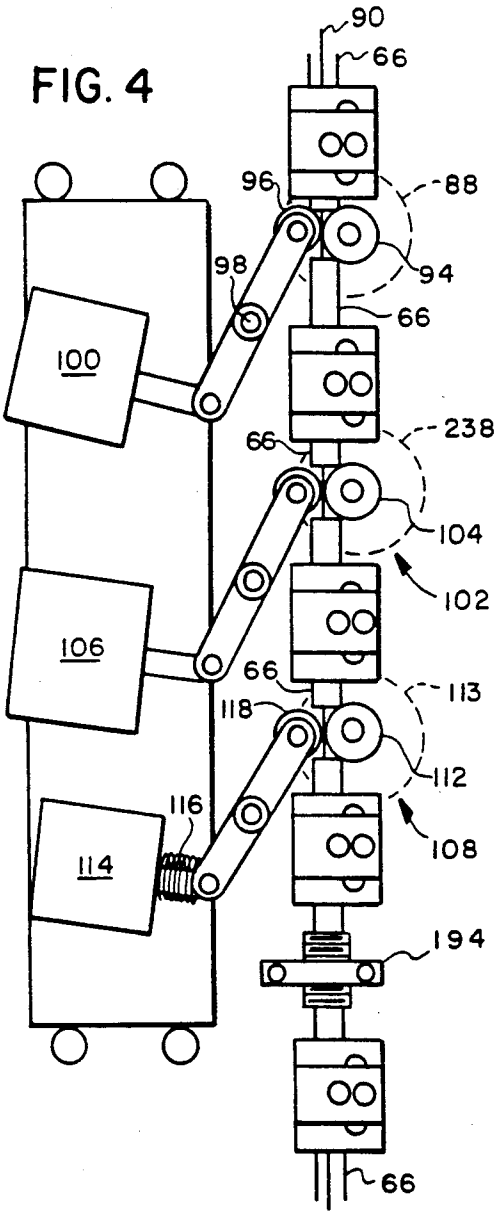
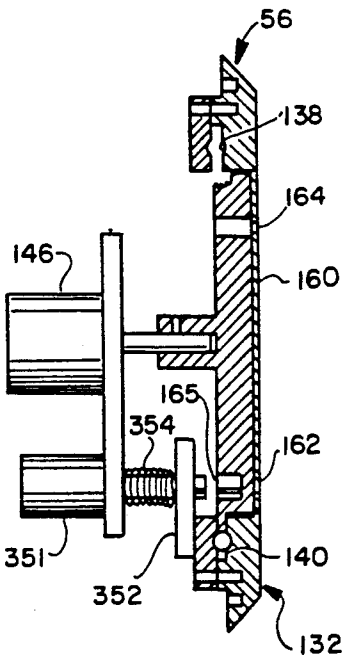


FIG. 7



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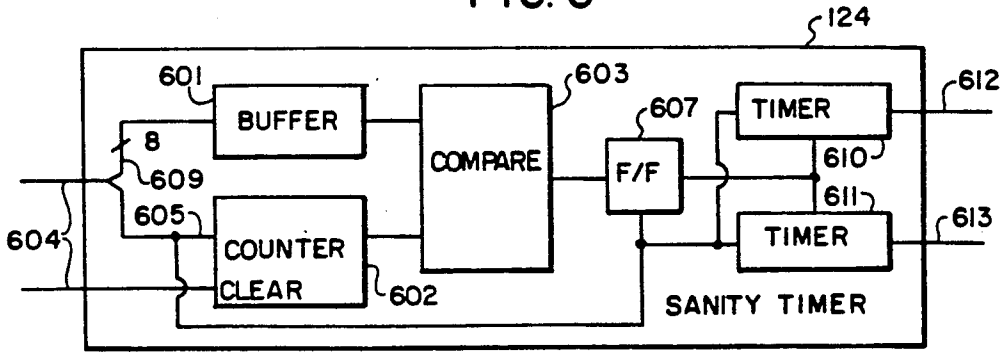


FIG. 5

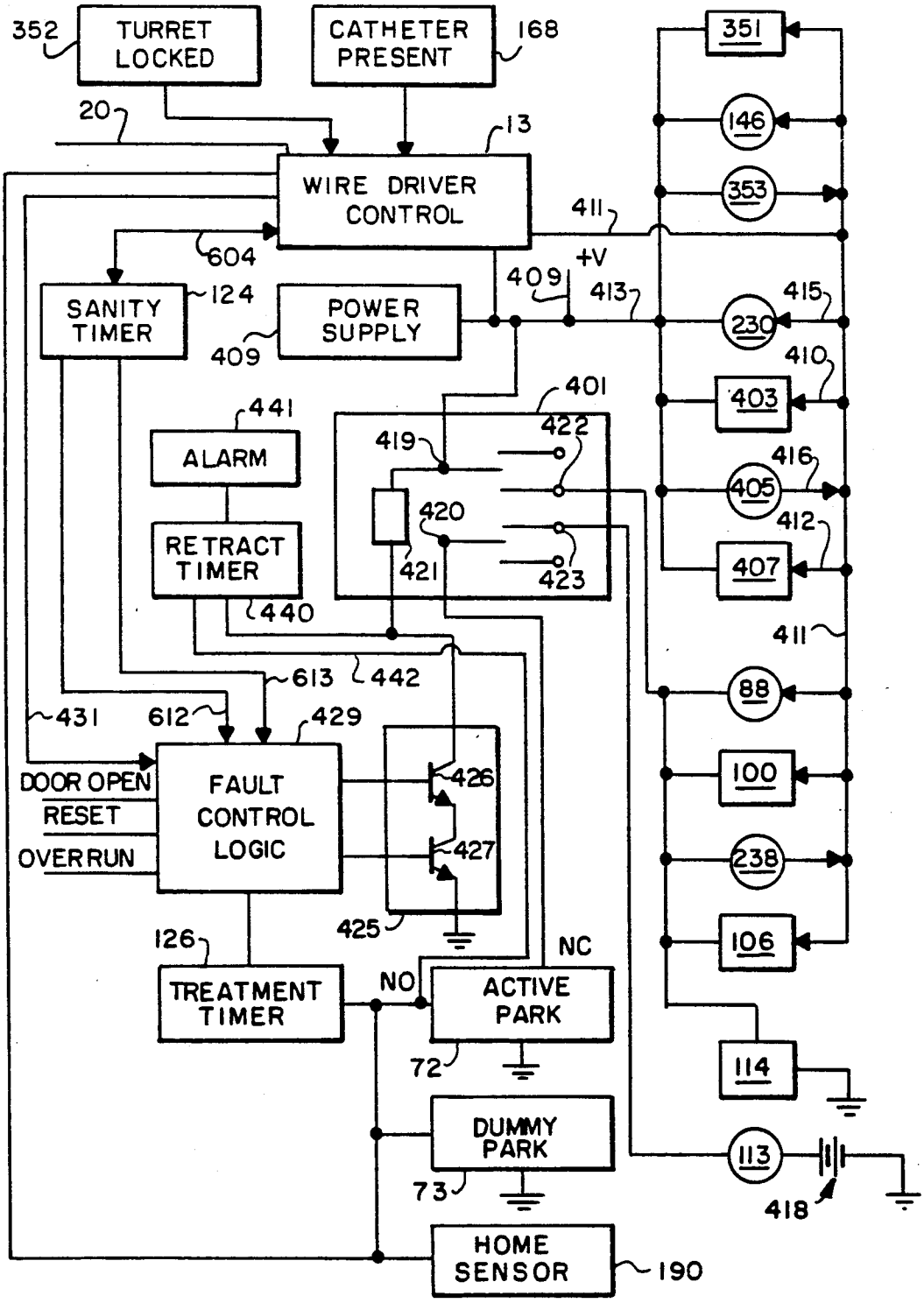

352
TURRET LOCKED
CATHETER PRESENT
168
20
13
WIRE DRIVER CONTROL
411
604
+V
409
413
SANITY TIMER
124
POWER SUPPLY
409
415
410
401
422
441
ALARM
419
416
420
RETRACT TIMER
421
423
412
440
411
613
442
431
612
429
DOOR OPEN
RESET
OVERRUN
FAULT CONTROL LOGIC
426
427
425
126
NC
TREATMENT TIMER
NO
ACTIVE PARK
72
DUMMY PARK
73
HOME SENSOR
190
351
146
353
230
403
405
407
88
100
238
106
114
113
418

FIG. 8

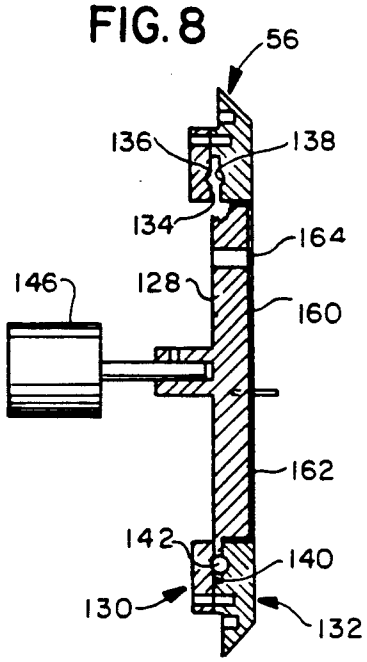


FIG. 12

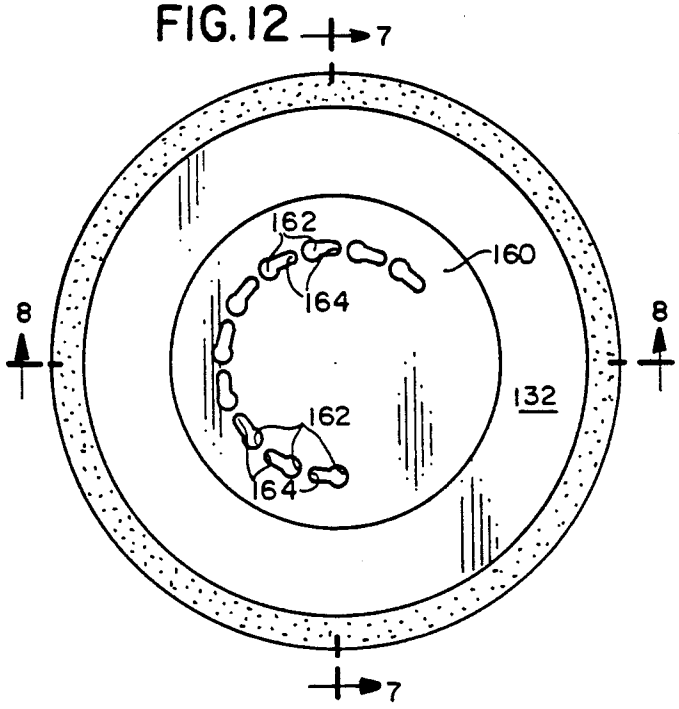
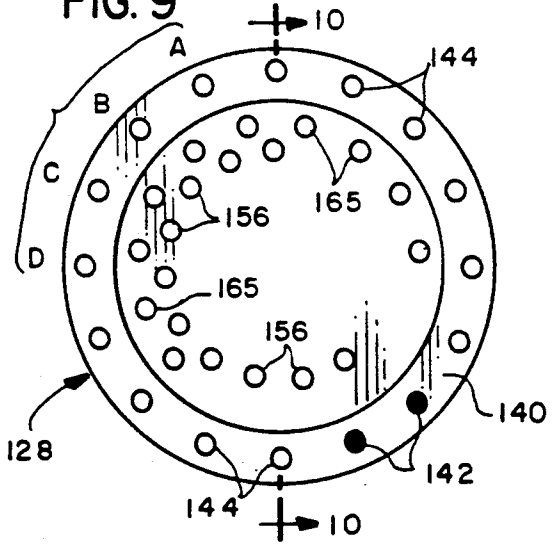


FIG. 9



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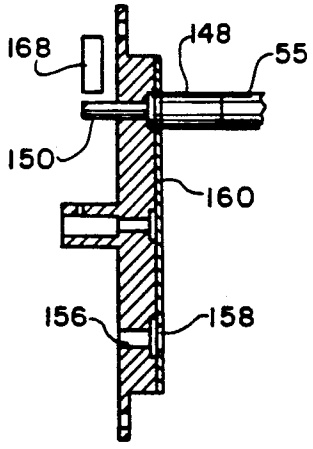

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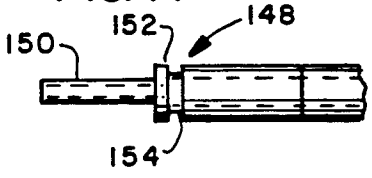


FIG. 13

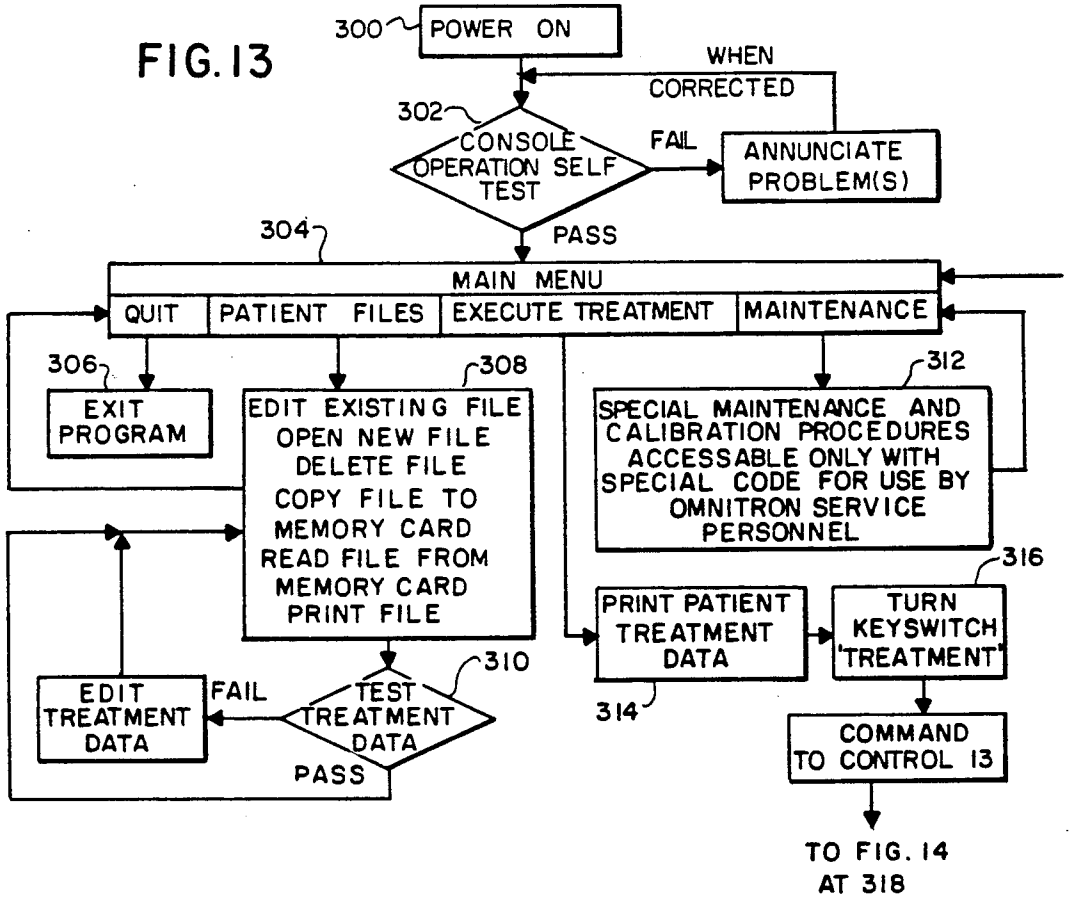

300
POWER ON
WHEN CORRECTED
302
CONSOLE OPERATION SELF TEST
FAIL
ANNUNCIATE PROBLEM(S)
PASS
304
MAIN MENU
QUIT
PATIENT FILES
EXECUTE TREATMENT
MAINTENANCE
306
EXIT PROGRAM
308
EDIT EXISTING FILE
OPEN NEW FILE
DELETE FILE
COPY FILE TO MEMORY CARD
READ FILE FROM MEMORY CARD
PRINT FILE
312
SPECIAL MAINTENANCE AND CALIBRATION PROCEDURES ACCESSABLE ONLY WITH SPECIAL CODE FOR USE BY OMNITRON SERVICE PERSONNEL
316
PRINT PATIENT TREATMENT DATA
TURN KEYSWITCH 'TREATMENT'
314
COMMAND TO CONTROL 13
EDIT TREATMENT DATA
FAIL
TEST TREATMENT DATA
310
PASS
TO FIG. 14 AT 318

FIG. 16

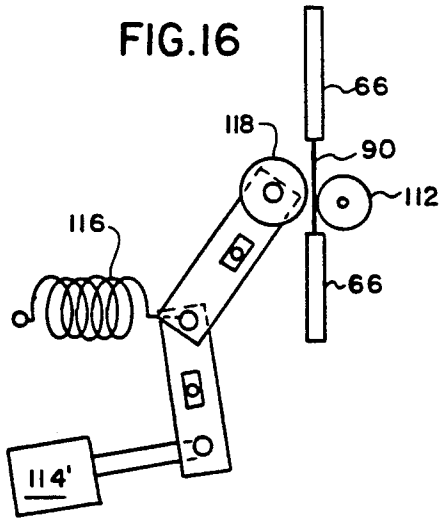

66
118
90
112
116
66
114'

FIG. 14

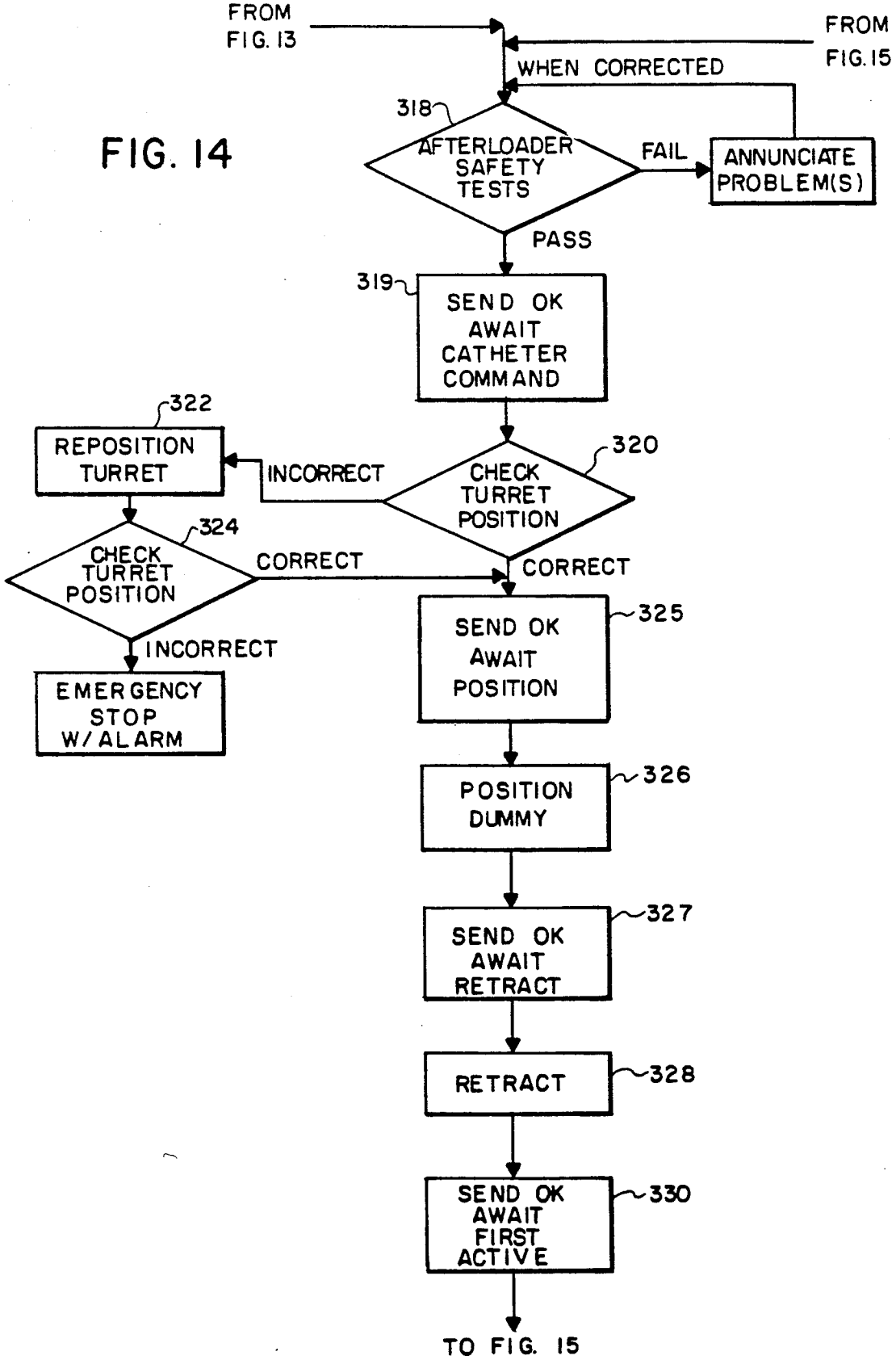
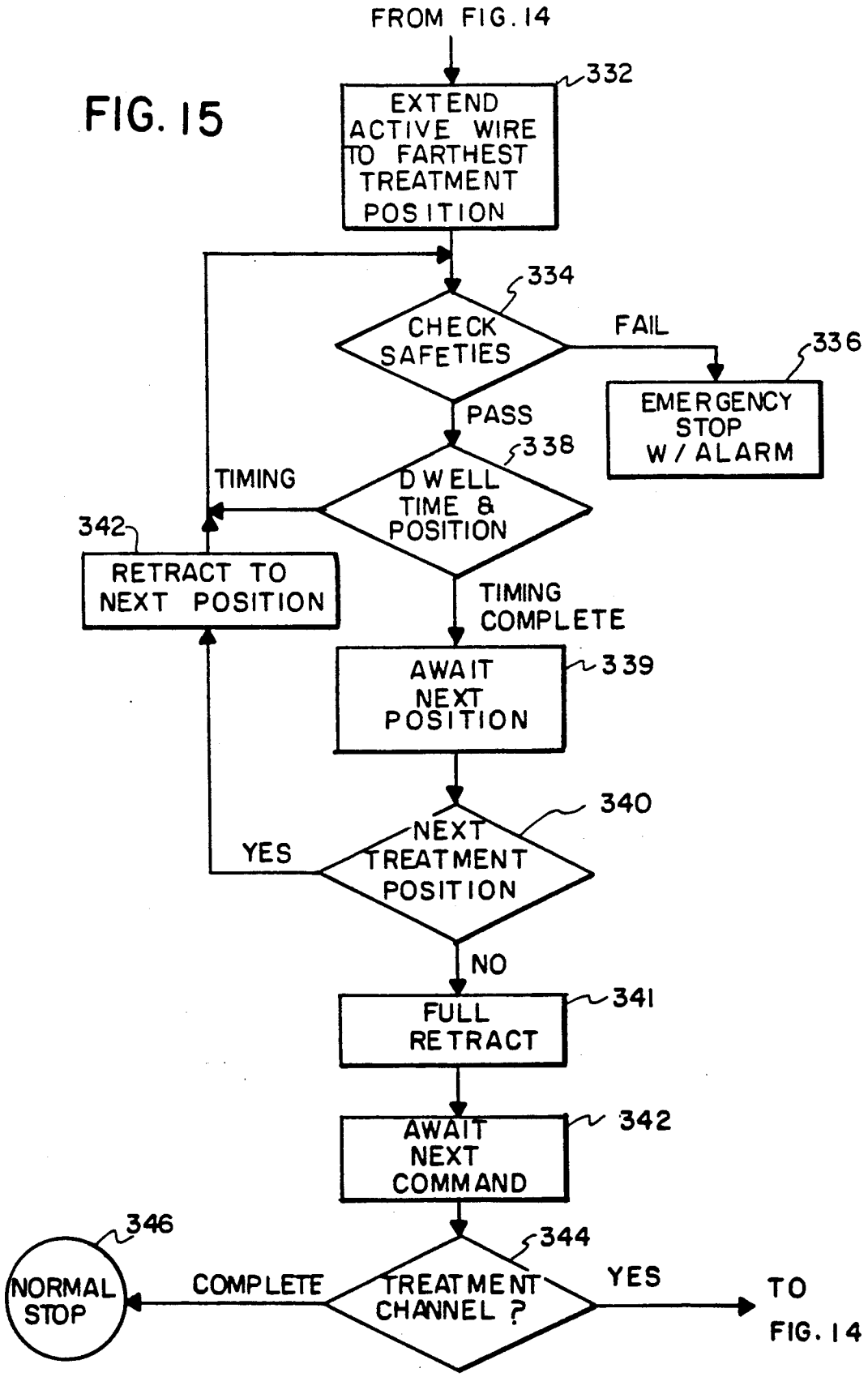

FROM FIG. 13
FROM FIG. 15
WHEN CORRECTED
318
AFTERLOADER SAFETY TESTS
FAIL
ANNUNCIATE PROBLEM(S)
PASS
319
SEND OK AWAIT CATHETER COMMAND
322
REPOSITION TURRET
INCORRECT
320
CHECK TURRET POSITION
324
CHECK TURRET POSITION
CORRECT
CORRECT
INCORRECT
EMERGENCY STOP W/ALARM
325
SEND OK AWAIT POSITION
326
POSITION DUMMY
327
SEND OK AWAIT RETRACT
328
RETRACT
330
SEND OK AWAIT FIRST ACTIVE
TO FIG. 15

FIG. 15


FROM FIG. 14
332
EXTEND ACTIVE WIRE TO FARTHEST TREATMENT POSITION
334
CHECK SAFETIES
FAIL
336
EMERGENCY STOP W/ ALARM
PASS
338
DWELL TIME & POSITION
TIMING
342
RETRACT TO NEXT POSITION
TIMING COMPLETE
339
AWAIT NEXT POSITION
340
NEXT TREATMENT POSITION
YES
NO
341
FULL RETRACT
342
AWAIT NEXT COMMAND
344
TREATMENT CHANNEL ?
YES
TO FIG. 14
COMPLETE
346
NORMAL STOP

APPARATUS AND METHOD FOR THE REMOTE HANDLING OF HIGHLY RADIOACTIVE SOURCES IN THE TREATMENT OF CANCER

BACKGROUND OF THE INVENTION

The present invention relates generally to methods and apparatus for the handling of high activity radioactive sources in the treatment of cancerous tissue.

The use of radioactive material in the treatment of cancer is well known in the medical field. Treatment techniques, however, vary dramatically depending upon the location of the cancerous tissue and the activity level of the radioactive source used in treatment.

One common treatment procedure involves the use of relatively low activity radioactive seeds. Due to their low activity levels, typically about 1 millicurie/centimeter, these seeds remain resident in, or adjacent to, the tissue undergoing treatment for extended periods of time, for example, several days. As a consequence, the seeds are surgically implanted, thereby allowing the patient to continue normal activities during the resident treatment period.

One of the principal advantages of such low activity treatment procedures is the ease of handling of the radioactive sources or seeds, themselves. While ordinarily stored in radioactive "safes" when not in-use, these low activity seeds may otherwise be handled freely by doctors and support personnel during implantation and removal. The disadvantages of this treatment technique, however, are long residency times and the requirement for surgical implantation and removal, the latter with its attendant trauma to adjacent normal tissue.

At the other end of the treatment spectrum are the high activity radioactive treatment procedures. These procedures, which typically employ radioactive sources in the range of 10 curies, present significant handling and treatment challenges. On the other hand, a significant offsetting advantage of such a treatment regime is its extreme speed. A complete treatment session can be completed in only a few minutes. The patient carries no radioactive implants within him from the treatment center.

A ten curie source cannot be openly handled or exposed to treatment facility doctors and personnel. Even relatively short exposures may result in radiation burns. As a consequence, high activity radiation therapy must be conducted remotely, with the radioactive source being removed from a shielded container or "safe" to the point of treatment, and thereafter returned, all by mechanical means.

It will be appreciated that apparatus for positioning high activity sources must be of uncommon integrity, accuracy, and reliability. It must have safeties, backups, and means for assuring that, in no event, can a source be lost, left behind, misplaced or, simply fail to retract into the safe, even for relatively short durations of time. The possibility for irreversible damage to normal tissue, in the time required for manual intervention upon system failure, is simply too great. As set forth in more detail below, the present invention describes a remote source afterloader having a high degree of reliability and emergency backup protection against system failure or loss of control.

The mechanical placement of high activity sources requires precise and accurate positioning both to assure proper dosage levels to cancerous tissue as well as to minimize damage to adjacent normal tissue. By reason of the intense radiation associated with high activity sources, real-time, hand-guided source placement by the treating physician is precluded. The source, therefore, is inserted through a tube, a needle, or catheter previously surgically positioned in the patient.

The use of catheters, although less invasive than the open surgical implantation of seeds, nevertheless traumatizes tissue along its path of insertion. In delicate tissue regions, for example, in the brain, such trauma must be kept to an absolute minimum. Known prior art high activity sources are affixed to the end of delivery wire of substantial diameter, typically in excess of 1 millimeter. As a consequence, the delivery wire and source must be inserted through correspondingly large tubes, needles or catheters.

Recent developments in high activity source manufacture have resulted in the availability of an ultra-thin iridium source of less than 0.5 millimeters in diameter which, in turn, permits the use of significantly narrower catheters. This source is disclosed in U.S. application Ser. No. 228,400, filed Aug. 4, 1988. In its preferred arrangement, the source comprises a 1 centimeter active region of relatively pure iridium positioned 1 millimeter from the end of 2.1 meter delivery wire. Such ultra-thin radiation sources, in combination with the present remote afterloader, now permit radiation treatment in, or proximate to, delicate tissue areas at heretofore unrealizable low trauma levels.

The present invention, therefore, is directed to a remote afterloader having the capability of properly advancing and positioning ultra-thin wire of 0.5 to 0.75 mm diameter with the utmost reliability and safety. It will be appreciated that these new ultra-thin source wires do not exhibit the same strength characteristics, particularly in buckling, as the more massive prior art wires. Thus, existing remote afterloader apparatus, which were developed for these heavier gauge wires, have proved unsuitable.

One such prior art device, for example, uses a drum onto which the delivery wire is wound, thereby retracting the wire from the catheter and patient. Extension of the wire, however, requires a smooth cylindrical shroud oriented around the outside of the drum against which the wire coil expands as the drum is rotated in the uncoiling direction. Upon contacting the shroud the wire is urged through a narrow opening or slit therein, then, into the catheter for delivery to a tumor site. This arrangement is wholly unsatisfactory for ultra-thin delivery wires. These wires simply do not have sufficient buckling integrity to permit the relatively unguided movement central to drum/shroud operation.

The present afterloader incorporates a dual-capstan drive arrangement in which one capstan positively feeds the delivery wire while the second capstan precisely meters wire movement. Importantly, the path of the delivery wire within the afterloader itself is tightly constrained, in both directions from the capstan drive assembly, thereby precluding buckling of the wire. More specifically, a low friction channel or tube having sufficient length to store all but the active tip region of the delivery wire is provided below the capstan drive. This channel is of minimum cross-section thereby precluding wire bending or deformation. Above the capstan drive, the delivery wire, including the iridium source, feeds into a narrow tubular structure defining the interior of a radioactive safe, then through a narrow outlet channel to a multiple catheter turret assembly. In

this manner, there are no open regions within the remote driver apparatus which might permit wire buckling during either extension or retraction.

The above wire containment structure serves another extremely important safety function. It is imperative to establish that the highly radioactive iridium source portion of the delivery wire is, in fact, safely retracted and stored within the safe. Failure to properly identify a non-stored condition could result in a severe overdose to the patient and to personnel who enter the treatment environment under the mistaken belief that the source has been properly retracted.

The present afterloader, by contrast, employs redundant systems to verify proper source storage. One of these systems, importantly, provides unfailing and absolute protection against wire over-retraction. Specifically, the end of the narrow wire channel is obstructed to preclude further wire travel thereby defining a maximum wire retraction limit. This position corresponds to proper stowage of the active region within the lead safe.

Abutting engagement between the delivery wire and channel end does not, however, insure that the active region of the wire has been safely stored. For example, were the delivery wire to sever, the inactive end could properly seat against the channel end while the active region remains outside the safe, possibly still within the patient.

The present afterloader includes a console computer at which an operator can enter a treatment plan for a patient. The plan is checked by the console and high level commands specifying source position within a patient and dosage duration are sent to a remote afterloader computer. The afterloader computer receives and implements the commands by controlling wire movement apparatus. The specific actions of the afterloader as well as its safety and integrity are the responsibility of the afterloader computer.

The present invention provides absolute protection against such false indications of wire storage. In this connection, the wire guide and storage channels additionally serve to facilitate highly accurate wire length measurement. Specifically, a "home" optical wire sensor is precisely placed near the channel outlet to detect the presence or absence of the wire. When a wire is extended, the length of the wire beyond the home optical sensor, as determined from the wire movement metering capstan, is closely monitored by a wire length count maintained in the afterloader computerized controller. Upon retraction of the wire past the home sensor, the wire length count is compared with the wire length count at the home sensor when the wire was first extended. If the retraction count is different from the extension count by more than a threshold value, fault signals are generated to notify operating personnel.

In addition to the absolute and unerring determination of active element storage, it is critical that the position of the active source be known at all times with high accuracy and reliability. Improper positioning now only endangers normal tissue, but may result in the failure to treat cancerous tissue. The remote afterloader control circuitry of the present invention provides a high degree of operational cross-checking with automatic wire retraction upon cross-check failure.

Wire delivery and position determination is predicated upon the previously noted dual-capstan arrangement in which a stepper motor which is controlled by the afterloader computer drives the first capstan and a position encoder, also connected to the afterloader computer, is driven by the second capstan. Each computer controlled step of the drive motor produces a precisely known axial movement of the delivery wire and, in turn, a corresponding and known response from the encoder. The output from the encoder is compared against the stepper motor commands, both on an incremental per step basis and on an overall basis. At the incremental level, the absence of proper encoder signals following one or more steps signifies a wire jam, and further wire delivery is terminated.

The afterloader computer further cross-checks the overall number of encoder output pulses actually received against the number of expected pulses based on the number of stepper motor steps commanded. A predetermined, but small, discrepancy is permitted between the computed and actual number of drive motor steps to account for capstan slippage. However, should encoder outputs cease entirely following stepper motor actuations or should the overall number of encoder outputs not fall within the predetermined limits, it is assumed that a delivery wire jam or obstruction has been encountered. In any event, the precise positioning of the wire cannot be assured under such conditions, and, therefore, the wire will be withdrawn. Withdrawal is first attempted by controlling the stepper motor to withdraw the wire. If the stepper motor fails to satisfactorily withdraw the wire, the stepper motor and wire movement capstan are disengaged and a separate retraction motor is energized to withdraw the wire.

The delivery of high activity radioactive sources requires afterloader apparatus comprising two distinct and separately located subsystems. First, the operator console is provided. This console is located in a room separate from the radioactive source thereby avoiding exposure of treatment personnel to radioactivity while the source is extended from its safe. The second subsystem, the remote afterloader, is the mechanical source storage and delivery apparatus which receives high level commands from the console and physically feeds the active source from the safe t precise locations within the patient, and for precise time intervals.

It is a critical feature and objective of the present invention to position the source accurately within a patient and then to withdraw the source, both steps to be performed with a high degree of certainty that the source is actually where it is supposed to be. As set forth above, the described apparatus provides the requisite accuracy as long as the afterloader computer control is properly functioning.

Computers, however, occasionally malfunction. Therefore, the present afterloader provides for monitoring of proper computer function and, in the event of computer or other malfunction, for the automatic emergency retraction of the radioactive source.

The emergency retraction system functions at the most basic circuit level, thereby virtually eliminating the possibility of emergency backup system failure. In the first instance, the emergency system operates from a constantly recharging backup battery source. This backup source is constantly monitored by the computer which, in turn, signals a backup power failure, simultaneously blocking extension of the active source wire until proper backup system operation has been restored.

The emergency retraction system requires no computer control. It does not utilize the normal capstan drive stepper motors, instead, a separate DC motor driven capstan is provided. Upon primary system failure, power is switched to this motor, thereby forcing

full wire retraction. Emergency retraction is timed by a retraction timer. When a retraction has taken longer than a preset time, an audible alarm is sounded to notify operating personnel. This emergency motor continues to operate until the inactive end of the delivery wire engages a switch positioned at the end of the wire storage channel.

Watchdog timers are provided within the remote wire driver subsystem to monitor the afterloader computer. In the event that valid reset signals from the afterloader computer control are not received within a preset interval, computer failure is assumed, and the automatic emergency retraction sequence is engaged. In an embodiment a redundant pair of watchdog timers is used for greater safety. Further, the timers are reset by a multi-bit binary word which follows a predetermined sequence from word to word. A received multi-bit word is compared at the timer with a predicted value and if the received word and the predicted value are not the same, the reset signal is considered invalid. A maximum treatment timer is also used which starts the emergency retraction system when the active source has been extended for more than an expected maximum treatment time.

Additional operational and apparatus subsystems are included to further assure proper overall system operation. One such subsystem is a wire delivery pretest subsystem. This subsystem assures proper active wire extension by first checking the path integrity of each catheter. This test is performed by extending a dummy wire through each catheter tracing the treatment profile intended for the active wire.

The dummy wire drive apparatus is substantially identical to that previously described for the active wire, although no emergency retraction system is incorporated. Thus, undue slippage or jamming of the dummy wire, or a failure to retract fully, signals a fault condition which precludes active wire extension. Importantly, this fault condition is registered, not merely by the computer afterloader, but in hardware interlocks of the remote wire driver apparatus itself, whereby extension of the active wire will be precluded even though the computer may have failed to register the fault condition.

A similar fault detection/protection arrangement is provided in connection with the optional multiple catheter turret. In this connection, the present invention may advantageously incorporate a turret arrangement permitting connection of up to ten separate catheters. In this manner, multiple catheters may be positioned within a patient to facilitate the more complete treatment of the cancerous tissue area in one radiation application session. Under afterloader computer control each catheter is accessed, in turn, and the appropriate pre-programmed treatment regime implemented. This regime includes the above described catheter pretesting by first extending the dummy wire.

It is imperative that no attempt be made to extend the dummy and active wires unless the turret is properly indexed at a valid catheter location having a catheter inserted therein. Consequently, detectors are provided to signal both the existence of the catheter and the proper indexing of the turret. Again, a turret or catheter fault condition is registered, not merely by the computer, but by the remote wire driver apparatus thereby assuring proper fault-induced inaction regardless of computer operation.

From the foregoing it will be apparent that the present invention provides for the control of remotely located radioactive source wire driver equipment. More particularly, apparatus for precisely positioning ultra-thin sources and delivery wires is provided such that the wire may be extended from, and returned to, a safe without likelihood of wire buckling. The proper storage of the active source within the safe is determined with high reliability and the active source is absolutely precluded from over-retraction. A low friction delivery wire channel serves to guide the wire, prevent buckling, preclude over-retraction, and aid in the detection of wire breaks. Emergency backup active wire retraction is provided in the event of computer or other malfunction. Dummy wire testing of all catheters is performed. A multiple catheter selection turret may be provided. Cross-fault detection is employed to preclude active and dummy wire extensions unless the other wire is properly retracted and parked and unless the turret is properly indexed to a valid catheter position. Other features of the invention are disclosed in the following figures, written specification and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block representation of the present wire afterloader illustrating the placement of the remote safe and wire driver in a treatment room separate from the control console;

FIG. **2** is a functional block diagram of the control console of FIG. **1**;

FIG. **3** is a left side elevational view of the remote wire driver of FIG. **1** with a portion broken away illustrating the placement of the active and dummy wire storage and guide channels and of wire drive assemblies and wire position detectors;

FIG. **4** is an expanded view of the wire movement apparatus of FIG. **3**;

FIG. **5** is a block diagram of the wire driver control circuitry;

FIG. **6** is a block diagram of a sanity timer of FIG. **5**;

FIG. **7** is a sectional view taken along line **7—7** of FIG. **12** of the catheter select turret assembly;

FIG. **8** is a sectional view taken along line **8—8** of FIG. **12** of the catheter select turret assembly;

FIG. **9** is a rear elevational view of the rotating turret of the turret assembly;

FIG. **10** is a sectional view taken along line **10—10** of FIG. **9** of the rotating turret further illustrating the placement of a catheter connector therein;

FIG. **11** is a side elevational view of a catheter connector;

FIG. **12** is a front elevational view of the catheter select turret assembly showing the catheter locking plate;

FIG. **13** is a flowchart depicting console computer operation;

FIGS. **14** and **15** are flowcharts depicting wire driver control operation; and

FIG. **16** is an alternative embodiment for a pinch roller control assembly of FIG. **4**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The remote afterloader of the present invention, as shown in its most general form in FIG. **1**, includes a computerized control console **10** located in a control room **12** and a remote safe and delivery wire driver **14** located in a treatment room **16**. Federal regulations

require, in view of the high radiation levels associated with high activity sources, that patients undergoing treatment be placed in shielded treatment rooms isolated from the attending physicians and other personnel. Thus, the treatment room **16** complies with appropriate federal regulations for shielding and, further, is provided with an entrance door interlock **18** to automatically retract, as discussed in more detail below, the active source upon entrance of non-patient personnel into the treatment room. A data and control bus **20** interconnects the console **10** with the remote drive **14**. The data and control bus **20** of the present embodiment is an RS 422 link which connects console **10** to a microprocessor controlled controller **13** of wire driver **14**.

FIG. **2** is a block illustration of the control console **10** which includes a computer **22** of conventional availability incorporating a color monitor **24**, a keyboard **26**, a printer **28** and a floppy disk drive **30**. More specifically, the computer is of the well-known 80386 processor variety and includes an additional 40 M-byte hard drive. An uninterruptible power supply **32** is provided to protect against losses of power during on-going treatment sequences. Uninterruptible power supply **32** also provides power to the wire driver **14**.

Also included with the console **10** of FIG. **2** are various annunciators and specific control function input buttons. Error **34**, horn **35**, safe **36** treatment room door open **38**, and armed **40** annunciators, as well as stop **42**, treatment **44**, and reset 122 keys and buttons are provided on the control console itself. A similar panel of annunciators and switches is provided at the treatment room door and at the remote wire driver. The later panels are both controlled from the wire driver controller **13**.

FIG. **3** illustrates various structural features of the remote driver **14** used to extend treatment wires into a catheter **55** for patient treatment. There are two delivery wires, one active and one dummy. Each is of approximately 0.5 millimeters in diameter. In the preferred arrangement, the active delivery wire has an overall length of 2.1 meters and contains a 10 millimeter long seed of activated iridium spaced 1 millimeter from the forward end thereof. The dummy wire is 1.8 meters in length and does not contain iridium seed.

The iridium seed of the active wire is typically irradiated to an activity level of 10 curies and, therefore, represents a potentially dangerous source of radiation that must be properly stored when not in use. A lead safe **58** is provided for this purpose. In the preferred embodiment safe **58** comprises a lead sphere having a radius of approximately 106 mm. Referring still to FIG. **3**, the safe **58** is provided with a 90 degree radius cylindrical channel **60** of sufficient diameter to pass the active wire source. The channel **60** defines a lower inlet **62** through which the active wire feeds from its guide and storage channel **66**, discussed in more detail hereinafter, and an outlet **64** from which the active wire source is extended, thereafter, through a turret **56** and into the active catheter **55**.

The active and dummy wire guide channels **66** and **67**, respectively, are made of stainless steel tubes which are connected by connectors **80** to a backing plate **76**. The overall length of the active channel **66** is selected such that the 10 mm active portion of the active wire **90**, i.e., the iridium seed, will be substantially centered in the safe **58** at its midpoint **68** when the opposed rearward wire end abuts a park switch **72** positioned at end **70** of the active channel. In similar fashion, the overall length of dummy guide channel **67** is selected such that the forward end of the dummy wire will be retracted to a non-interfering position **69** when the opposed rearward end thereof abuts a dummy park switch **73** at channel end **71**. The channels **66** and **67** are broadly radiused, preferably to about 80 mm, to minimize wire friction therewith.

It should be note that other channel constructions are contemplated by the present invention. Any construction providing for the low friction storage of a predetermined length of delivery wire, and without substantial openings or volumes into which the wire might buckle, should be satisfactory.

Referring to FIG. **3**, the respective active and dummy wire channels merge in a "Y" or wishbone channel connector **82**, thereafter forming a single output channel **83** operatively interconnected with the turret **56**. The wishbone connector **82** is milled to the ultimate channel working dimension through which the respective active and dummy wires pass directly.

The active wire drive and emergency retraction system **84** is shown in FIG. **3** and in enlarged form in FIG. **4**. The dummy wire drive system **86** is identical, except that the emergency retract motor **113** and its drive assembly **108** is omitted. The uppermost capstan **94** and pinch roller **96** define the stepper motor **88** wire drive assembly. Stepper motor **88** is beneath backing plate **76** and is shown in dotted lines Under computer stepper control from wire driver control **13**, stepper motor **88** moves the active wire **90** along the previously identified path **66** in both the extension (upward) and retraction directions. As described in more detail below, the active wire is extended to the maximum treatment position then, as required by the prescribed treatment profile, retracted in precisely timed intervals of predetermined distance until the entire treatment cycle for the given catheter has been completed.

As shown in FIG. **4**, the stepper motor **88** drive assembly includes a rubber surfaced capstan **94** which is rotated by the stepper drive motor **88**. A rubber pinch roller **96** is pivotally mounted at a pivot **98** and urges active wire **90** against the capstan **94** when pull-type solenoid **100** is energized. As can be seen in FIG. **4**, sections of the guide channel **66** have been removed so that the pinch roller **96** and capstan **94** can physically contact the drive wire **90**. The remaining sections of channel **66** guide the wire **90** so that it remains substantially straight and runs parallel to the plane of capstan **94** rotation.

Below the drive capstan **94** is the encoder drive assembly **102**. It is substantially identical to the above described wire drive assembly except that an encoder **238** which is connected through plate **76** to an encoder shaft or capstan **104** is substituted for the stepper drive motor **88**. When active pull-type solenoid **106** is energized and moves a pinch roller to engage the wire **90** with capstan **104**, movement of the wire **90** rotates capstan **104**. Encoder **238** responds to the rotation of capstan **104** by sending wire movement indicating pulses to controller **13** which uses the pulses to track the position of the active source in wire **90**.

The lowest capstan, used only in connection with the active wire drive and retract system **84**, defines the emergency retract assembly **108**. This assembly differs from the stepper motor drive assembly in two important aspects. First, the capstan **112** is driven from a conventional, non-stepper type DC motor **113**. Second, the pinch roller controlling solenoid **114** is of the push-type

and includes a spring **116** which biases a pinch roller **118** against the capstan **112**. Solenoid **114** power is required to retract the pinch roller **118** thereby disengaging the wire **90** from the emergency retract capstan **112**. In the event of a computer failure, power failure, or other system loss of control, power is dropped to emergency retraction solenoid **114**, thereby automatically engaging the wire **90** with emergency retraction capstan **112**, while emergency battery power is simultaneously applied to emergency retraction motor **113**. As this is a conventional DC motor, no special control or stepping instructions are required. Emergency retraction may be effected even though other portions of the afterloader system, including the computer **22** and controller **13** are inoperative.

Alternatively, emergency retraction assembly **108** could be constructed using a pull-type solenoid **114'** and a jointed pinch roller control arm as shown in FIG. **16**. In FIG. **16** components performing the same function as in FIG. **4** are given the same reference number.

Two over-travel optical sensors provide an additional level of protection and redundancy to the system. These sensors **194** and **195** (FIG. **3**) are mounted along respective active and dummy wire channels **66**, **67** immediately below the wire drive systems **84** and **86**. The computer control system is pre-programmed to accept a maximum treatment profile well below the 2100 mm length of the active wire, e.g., 1500 mm, thereby assuring that some portion of the wire will always remain adjacent the respective over-travel sensor. Therefore, the detection of a "no wire" condition by either over-travel sensor **194**, **195** necessarily signifies system malfunction terminating treatment and mandating emergency active wire retraction.

An additional optical sensor **190**, called the home sensor, is placed in channel **83** to detect the presence and absence of a delivery wire. The home sensor **190** is the index point against which source positioning is measured. The home sensor is used to detect when a drive wire tip passes the home sensor point both on extension and retraction. Sensor **190** transmits signals indicating the presence or absence of a wire at the home position to control **13**.

The catheter turret **56**, which is shown in FIGS. **7** through **12**, comprises a turret **128** (FIG. **8**) retained for rotating movement between inner and outer race members **130** and **132**, respectively. Race members **130**, **132** are rigidly affixed to the housing of the remote wire driver **14** and define an annular channel **134** therebetween. A pair of radius grooves or races **136** and **138** are formed in opposed channel surfaces of the race members.

An annular flange **140**, integrally formed on the perimeter of turret **128**, is received within the channel **134**. A plurality of ball-type bearings **142** are seated within holes **144**, which holes are evenly spaced around the turret flange. Bearings **142** travel within races **136**, **138** thereby permitting the smooth rotation of the turret **128** under the computer driven control of a stepper motor **146** attached thereto.

Placement and locking of catheters **54** into the turret assembly **56** is best illustrated in FIGS. **8–12**. As shown in FIG. **11**, the end of each catheter is provided with a connector **148** defined, in part, by a cylindrical extension member **150**, an annular locking flange **152** and a recess **154**. A plurality of complementary catheter receptacle holes **156** are evenly spaced (FIG. **9**) around a diameter of turret **128**. Each hole includes a region of widened diameter **158** (FIG. **10**) adapted to receive a catheter locking flange **152** therein.

A circular catheter locking plate **160** is mounted adjacent the outside of the turret **128** for limited rotation with respect thereto. As shown in FIG. **12**, the locking plate **160** is provided with a plurality of holes **162**, with narrowed annular extensions **164**, the holes having spacings corresponding to those of the catheter holes **156** in the turret. Thus, the locking plate may be rotated to admit passage and positioning of one or more catheters in the turret. Following catheter insertions, the locking plate **160** is rotated until the narrower annular extensions **164** are received within catheter connector recesses **154** thereby locking all catheters against inadvertent removal.

It is essential to establish the existence of a catheter in the active catheter position **55** as a prerequisite to wire extension, particularly extension of the active wire. The active catheter position is defined by the uppermost hole **156** of the turret **128**, so long as that hole is properly aligned immediately above the turret/stepper motor axis. In this position, a wire extended from the output channel **83** (FIG. **3**) directly enters the active catheter **55** mounted adjacent thereto.

FIG. **10** illustrates the orientation of a catheter **54** in the active catheter position **55**. An optical catheter-in-place sensor **168** is mounted to the fixed inner race **130**, immediately above the active catheter position. Optical sensor **168** includes an optical source, pointed downward and an optical receiver for receiving reflected light from beneath the sensor. When the cylindrical tip member **150** of a catheter connector extends inwardly from the turret, light from the source of optical sensor **168** will be reflected and returned to the receiver. A signal indicating the receipt of reflected light is sent to control **13**.

Before the wire is extended into a catheter, it is important to assure that the turret **128** will not rotate during treatment. The inside face of turret **128** includes a plurality of cylindrical locking apertures **165** (FIG. **9**), which are angularly spaced the same as catheter receiving holes **156**, but rotated from the catheter holes by approximately 90°. As shown in FIG. **7**, the turret assembly includes a locking solenoid **351** which is structurally connected to the turret drive assembly. Solenoid **351** has a shaft **354** which is of suitable diameter to engage the holes **165**. When a catheter is placed in the active position **55**, solenoid **351** is energized to thrust shaft **354** into a hole **165**. Advantageously, the outward end of shaft **354** may be tapered to promote engagement with a hole **165** and to slightly correct the position of the active catheter. The assembly of FIG. **7** also includes an optical sensor **352** which, by means of an aperture (not shown) in shaft **354**, senses the seating of shaft **354** into turret **128**. A signal representing such seating is sent from optical sensor **352** to control **13**.

Turret **56** is rotationally positioned by the cooperative action of a stepper motor **146** and a rotation sensing optical encoder **353** (FIG. **3**) rotationally coupled at **355** to the stepper motor. Encoder **353** transmits to wire drive control **13** a series of signals indicative of its rotation and sends an index position signal once per 360° rotation. The index position signal, which is common to rotational encoders, is used to align the components of turret **56** during assembly and to identify a "home" catheter aperture **156** at the beginning of each treatment During assembly, the turret shaft is rotated until the index signal is generated by encoder **353**. The turret **128**

is then mounted to the shaft with a first (home) catheter hole aligned with the output of guide tube **83**. Thereafter, the index signal from rotational encoder **353** is used to identify the home turret position.

When turret **128** rotation is desired, control **13** sends stepper pulses to stepper motor **146** until the index signal is generated by encoder **353**. The number of stepper control pulses between the home catheter position and the destination catheter position, can then be sent to stepper motor **146** to achieve the proper rotation to place the destination catheter at the active location. The output signals from encoder **353** are used by control **13** during such rotation to check the actual turret rotation accuracy.

Treatment begins when an operator enters, at console computer **22**, a treatment plan for a particular patient and the catheters connected to that patient are attached to the connectors **156** of turret **56**. The treatment plan specifies which turret connectors, i.e., which catheters, are to receive treatment, the location of treatment in distance from the home sensor **190**, and the length of time for each treatment. After entry of the plan, console computer **22** runs diagnostic tests, checks the treatment plan for accuracy and safety.

After safety checks by the console computer **22**, it transmits a message over RS422 link **20** to wire driver control **13** of remote wire driver **14**. FIG. **5** is a block diagram of the control circuitry included in wire driver **14**. The message on link **20** is received by controller **13** of the remote wire driver **14** which in response, performs a number diagnostic and safety tests within remote wire driver **14**. A response message is then returned to computer **22**, indicating the success of the tests. Console computer **22** then responds by identifying the first turret connector (catheter) which is to receive treatment. Wire driver **14** responds to this message by checking to see that both the dummy and the active wires are in their fully withdrawn positions as indicated to control **13** by the signals from active park switch **72** and the dummy park switch **73**. Wire driver control **13** then transmits stepper motor control signals on a multiconductor bus **411** to stepper motor **146** to first "home" the turret then place the first treatment catheter, e.g., **55** in the active position to receive the active or dummy wire from wire driver **14**. As stepper motor **146** rotates the turret, the turret motion is sensed by encoder **353** and reported via bus **411** to wire driver control **13** which tracks the rotation. When catheter **55** is in the active position, wire driver control **13** transmits an activation signal to solenoid **351** which drives the locking pin **354** into place. Wire driver control **13** then checks locking pin detector **352** and catheter present detector **168** to determine if the turret is properly locked in place and if a catheter, e.g., **55** is in the active turret position.

In order to properly check the safety of the treatment, the console computer **22** next sends a command specifying that the non-radioactive dummy wire is to be moved to the maximum treatment distance and withdrawn. Wire driver control **13** responds to the command by grounding dummy wire drive solenoid **403** and dummy wire encoder solenoid **407** over conductors **410** and **412**, respectively, of multi-conductor bus **411**. The other terminals of solenoids **403** and **407** are permanently connected to a positive voltage supply **409** via a conductor **413**. Accordingly, both solenoids **403** and **407** are energized to engage the dummy wire between their respective pinch rollers and capstans. Wire driver control **13** also begins to transmit stepper motor control signals over communication path **415** of bus **411** to advance the dummy wire by rotating dummy wire stepper motor **230**.

As the dummy wire moves, it rotates capstan **417** of dummy wire encoder **405**. The movement of capstan **417**, and thus the movement of the dummy wire, is detected by encoder **405** and reported to wire driver control **13** over path **416** of bus **411**. Wire driver control **13** stores a wire position value and continuously updates this value in response to the signals from encoder **405**. Control **13** also surveys the rate of wire movement signals from encoder **405** to make sure that the dummy wire is moving at substantially the same rate that stepper driver **230** is being commanded to move it. Should the wire not be moving at an appropriate rate, slippage is indicated and stepper motor **230** is commanded by wire driver control **13** to reverse and thereby retract the dummy wire.

Assuming that the dummy wire is advancing at an appropriate rate, it will shortly be connected to guide tube **83** by connector **82** (FIG. **3**) and passed through home sensor **190**. Home sensor **190** is an optical sensing means which detects when the tip of a wire, either the active wire or the dummy wire passes therethrough. When the wire passes through home sensor **190**, wire driver control **13** records a count called the home count which represents the wire position value when the tip of the wire passed the home sensor. As the wire continues to move into and out of the catheter, the wire position value is incremented and decremented in response to signals from encoder **405**.

Console computer **22** specifies treatment positions in terms of distance from the input of the catheter (output of the wire driver). A known guide tube distance, called the offset, exists between the home sensor the wire driver outlet. Due to the offset, a treatment distance specified in a command is reached when the wire movement value, minus both the home count and the offset, equals that specified treatment distance.

The dummy wire continues to advance through the turret into the treatment catheter **55** until the maximum treatment distance has been reached by the tip of the dummy wire. Wire driver control **13** then reverses the direction of rotation of stepper motor **230** to begin withdrawing the dummy wire back into wire driver unit **14**. When the tip of the wire again passes home sensor **190** in the withdrawal direction, wire driver control **13** is notified. The amount stored in the wire position value should be substantially equal to the home count which was recorded when the dummy wire interrupted sensor **190** during the wire extension operation. If these numbers are within a predetermined threshold of one another, the process is assumed to be accurate and the dummy wire continues to be withdrawn until it parks against park switch **73**. Wire driver control **13** is notified when the dummy wire changes the position of park switch **73** and ground is removed from the solenoids **403** and **407**. Also, no new control signals are transmitted to stepper motor **230**. After the proper operation of the treatment apparatus is determined by the extension and withdrawal of the dummy wire, wire driver control **13** is ready to perform the requested treatment using the active source wire **90**. Active wire **90** movement is performed substantially as described above except that the drive apparatus **84** of the active wire is used.

Due to the increased hazards involved in extending the radioactive wire **90**, an emergency shutdown and

wire retraction system is included in the apparatus of FIG. 5. A safety relay **401** is the heart of the emergency shutdown and active wire retraction system. Upon the automatic detection of any system abnormality or difficulty, or upon the manual intervention by a system operator through the actuation of a stop button, the relay **401** is immediately de-energized and remains de-energized until the cause of the problem has been corrected and the operator resets the system. When relay **401** is de-energized power is removed from the stepper motor control portion of active drive assembly **84** and retraction motor **113** is energized to withdraw the active wire **92**.

The relay **401** is directly interconnected with both the emergency retraction DC motor **113** and to the emergency retraction capstan solenoid **114** thereby instantly commencing the emergency retraction cycle. Upon relay **401** deactivation power is removed from the retraction solenoid **114** and power from the emergency backup battery **418** is applied to the emergency retraction motor **113**. The emergency retraction cycle continues until the active wire **90** is fully retracted, as determined by wire engagement with the park switch **72**.

Relay **401** includes a plurality of stationary contacts **422** and **423**, a pair of movable contacts **419** and **420** and a coil **421**. Coil **421** is energized for normal operation by connection to the power supply **409** and to ground via a fault interrupter circuit **425**. Fault interrupter **425** comprises a pair of transistors with their emitter-collector paths serially connected. Both transistors, in normal operation, receive from fault control logic **429** high level signals at their bases so that low resistance path is presented from coil **421** to ground. When coil **421** is energized, armatures **419** and **420** of relay **401** are pulled down so that armature **419** connects power from power supply **409** to stationary contact **422** which is connected to active drive stepper motor **88**, active drive enable solenoid **100**, encoder **238**, encoder solenoid **106** and emergency retract solenoid **114**. While relay **401** remains energized, the active wire drive is capable of moving the active wire **90** as directed by wire driver control **13** and retraction solenoid **114** is energized to release any engagement with active wire **90**.

When a fault occurs, fault control logic **429** removes the high level signal from the bases of one or both of the transistors **426** and **427**, de-energizing relay **401**. In the de-energized state, the armature of relay **401** moves up and contact **420** touches contact **423** which is connected to the minus or ground terminal of DC retraction motor **113**. The positive terminal of retraction motor **113** is directly connected to battery **418**. Contact **420** of relay **401** is connected to ground via the normally closed contact of active wire park switch **72**. Should relay **401** be de-energized while active wire **90** is extended, power is removed from the active wire stepper drive **84** including the retraction solenoid **114** and ground is applied to retraction motor **113** via relay **401** and active park switch **72**. Releasing solenoid **114** engages the DC retraction capstan **112** with active wire **90**, and grounding the motor **113** starts the retraction operation. When the end of active wire **90** presses park switch **72**, the active wire is safely stored in the drive apparatus and the ground connection is removed from motor **113** to stop its retraction operation.

A timer **440** is activated during each emergency retraction to time the retraction and cause an audible alarm when the retraction is not completed within approximately 30 seconds. Retraction timer **440** is normally kept idle by the low level signal at the collector of transistor **426**. When this collector goes high, as will be the case when relay **401** is de-energized timer **440** begins to time a 30 second interval. The return of active wire **90** into contact with park switch **72** generates a reset signal which is connected via conductor **442** to timer **440**. The reset signal on conductor **442** will clear timer **440**, if it is received within the 30 second time out interval. If it is not received within the 30 second interval, a signal is sent from retract timer **440** to an alarm **441** which notifies operating personnel by means of an audible alarm signal.

Fault control logic **429** responds individually to a plurality of fault signalling conditions by removing the high level signals from the bases of transistors **426** and **427**. Among the signals which result in de-energizing relay **401** are signals from door open switch **18**, a reset switch on the control panel of wire driver **14** (not shown) overrun detector **194**, and signals requesting retraction received from control **13** on a conductor **431**. Fault control logic **429** also de-energizes relay **401** in response to signals from a pair of activity timers **124** and **126**.

The first of the activity timers, timer **124**, monitors the ability of wire driver control **13** to function. Control **13** transmits a periodic signal on a bus **604** approximately once every 100 milliseconds, but only when the computer hardware and software are functioning properly If this signal is lost for more than about 100 milliseconds, the timer **124** sends a fault signal to fault control logic **429** which, in turn, releases the relay **401**.

The activity timer **124** actually comprises a pair of redundant 100 millisecond timers **610** and **611** (FIG. 6). Unless reset every 100 milliseconds by signals from control **13**, each timer **610** and **611** will generate a time-out signal on a respective one of conductors **612** and **613**. Such time-out signals are connected to fault control logic **429** and cause de-energization of relay **401**.

The reset signals from control **13** comprise 8 binary digits and a strobe signal. To constitute proper reset signals, a given reset signal must be exactly one greater than the immediately preceding reset signal. The 8 bit reset signal portion is received on path **609** of bus **604** and stored in a buffer **601**, the outputs of which are applied to an 8 bit comparator **603**. Timer **124** also includes an 8 bit counter **602** which counts modulo **256**, the incoming strobe signals which are connected to counter **602** via path **605**. The outputs of counter **602** are also applied as inputs to comparator **603** where the counter bits are compared with the contents of buffer **601**. When the compared values match, which they should during normal operation, a logic 1 reset signal is transmitted by comparator **603** to a flip-flop **607** which buffers the reset signal and conveys it to timers **610** and **611** before they time out Alternatively, when the values of counter **602** and buffer **601** do not match, indicating system error, a logic 0 signal is generated by comparator **603** and timers will transmit fault signals to fault control logic **429** when they time out. The counter is initially synchronized with the reset signals from control **13** by a clear signal transmitted to counter **602** on bus **604**. The requirement that the 10 millisecond reset signals follow a prescribed sequence provides great assurance that control **13** is functioning properly.

The second activity timer **126** commences timing whenever the active wire **90** is extended. That is, whenever the active wire is not pressing the active park switch **72**. A maximum time of about 20 minutes is

allotted for active wire extension which time limit exceeds the duration of the longest treatment profile anticipated. Failure of the active wire to return to the parked position at least once every 20 minutes indicates a problem necessitating emergency active wire retraction.

For the purposes of the treatment timer **126** oversight, the park switch **72** signals the full retraction or parking of the active wire. In the absence of the required park signal within the predetermined time limit, the timer **126** signals fault control logic **429** which releases relay **401**.

It will be appreciated that the above described run safety relay **401** system provides a highly reliable means for forcing the immediate retraction of the active wire **40** in the event of computer or other failure. Importantly, this system is self-contained on the remote driver **14** chassis; and is of simple design thereby minimizing likelihood of failure; and incorporates backup power to further eliminate the possibility of emergency retraction failure.

FIGS. **13** through **15** illustrate overall computer controlled operation of the present remote wire afterloader system. Upon system power-up **300** and initial console self-test **302**, a main menu **304** permits optional courses of action including exiting the program **306** thereby permitting use of computer **22** for other tasks.

Patient treatment information, including the proposed treatment profile, must be entered **308**. Such profiles typically include a listing of each treatment position, by distance measured from the catheter outlet of wire driver **14**, as well as the treatment dwell time at each such position.

This information is checked **310** to verify, for example, that the selected profile does not violate system or medically based operational rules. Specifically, in its present and preferred arrangement, profile parameters must not include treatment positions exceeding 1500 millimeters or position dwell times exceeding 60 seconds. Further, the dwell positions must be arranged in descending order and not be closer together than a predetermined distance as specified during system initialization, i.e., at **312**.

The requirement for descending order dwell positions is important to proper operation of the present afterloader particularly in view of the extremely fine diameter wire for which the present system is intended to operate. Notwithstanding the dummy wire pretesting of each catheter to verify that an ultra-thin wire can be moved to the requisite dwell positions, there always remains some possibility than an ultra-thin wire will become jammed precluding further inward movement.

On the other hand, once a wire has been inserted to its maximum treatment position, the likelihood of jamming upon the retraction of that wire is extremely small. Therefore, it is preferable to commence treatment at the maximum dwell position whereby the active wire may immediately be retracted should the computer detect undue wire slippage at the drive capstan. This condition, as noted, is sensed by comparing the rate of wire movement detected by the encoders e.g., **238** with the rate of wire movement requested of the stepper motors e.g., **88**.

A maintenance capability **312** is accessible to qualified personnel for the purpose of source loading, unloading, calibration, and the setting of treatment profile parameter limits such as maximum dwell time and minimum dwell step sizes.

A patient treatment record, including proposed treatment profile, is printed **314** prior to each treatment session. Actual initiation of a treatment session requires actuation of a key switch **316** by the doctor or other personnel having appropriate authority.

The computer **22** then transmits an enable treatment command to control **13**. The control **13** then performs a number of safety tests **318** (FIG. **14**) in response to the enable command. Specifically, the control **13** verifies at **318** that the treatment room door is closed; that the console-to remote driver communications bus **20** is functioning; that both active and dummy wires are parked; that the wire position sensors are functioning; and, that the emergency backup battery voltage is proper.

After satisfactorily passing the tests of **318**, wire driver control **13** returns a command completed or OK message to computer **22** at block **319** and awaits the next command which will be a catheter select command, specifying a catheter location. Upon receipt of the catheter command, the turret position is set and checked at **320** by "homing" the turret, controlling stepper motor **146** to rotate to the specified position and locking the turret **128** by the solenoid **351**. The turret is repositioned at **322** and rechecked at **324** if the initial position is not correct. During steps **320** and **324** the turret is also checked for the presence of a catheter in the selected position.

In step **325**, another command complete message is sent to computer **22** and wire driver control **13** awaits a dummy position command specifying a dummy wire position in block **325**. When the dummy position command is received, wire driver **14** tests the first catheter position by cycling the dummy wire at **326**. The wire driver control **13** selects the dummy wire by grounding drive solenoid **403** and outputting a series of stepper motor commands sufficient to move the dummy wire approximately 5 millimeters beyond the dwell location specified for the catheter under test.

More specifically, the driver control **13** first calculates the number of steps required to extend the wire to the desired maximum position (including the 5 millimeter overextension) and the corresponding number of pulses expected from the dummy wire encoder **405**. These calculations are based on a reference point defined by the home optical sensor **190**, located adjacent the turret. Stepping of the dummy stepper **230** motor now commences and continues until the specified dummy wire position is achieved.

During dummy wire extension, the control **13** is performing cross-checks to verify that no obstructions or jams have been encountered. First, wire jams are determined by comparing the number of encoder **405** pulses received per stepper motor step. Advantageously, this test may be performed only after a predetermined number of steps have been taken to save computer resources. In the present embodiment, such a comparison is performed after each block of **33** stepper motor steps. If pulses stop, or fall below the expected rate, the wire is retracted and a jam condition is annunciated.

After achieving the specified dummy wire position, wire driver control **13** sends an OK signal, and awaits a retraction signal at **327**. The dummy wire is fully retracted in block **328** to terminate the dummy wire test cycle. Upon retraction, the length of the dummy wire is again checked to confirm that the wire has not broken. This check is performed by comparing the stored home count with the wire movement value which should be

substantially equal. The wire driver control **13** signals the successful completion of retraction to computer **22** and awaits an active wire command in block **330**.

The active wire command from computer **22** specifies the maximum treatment position for the active wire. The active wire is then extended to the furthest treatment position at **332** (FIG. **14**). Extension of the active wire is substantially identical to that of the previously described dummy wire. The wire is then precisely positioned at the first treatment location by, as before, first over-extending the wire by approximately 5 millimeters. Wire jamming and obstruction tests are performed again, as outlined with reference to extension of the dummy wire.

During the treatment phase, the control **13** continues to monitor system safety indices at **334**, including the long term watchdog timer **126**. Since the active wire is fully retracted and parked between each catheter treatment profile, this timer reflects active wire extension beyond the maximum treatment profile allowed by the computer. In short, this timer flags a potentially hazardous condition necessitating emergency retraction at **336**.

Upon completion of the pre-programmed dwell time for each active wire position at **338**, an OK message is sent and a new treatment position is awaited in **339**. Control **13** checks to see whether there are further treatment positions for that catheter at **340**, if so, the active wire is withdrawn to the specified next adjacent dwell position at **342**.

Following the last treatment or dwell position for each catheter, the active wire is fully retracted in **341**, checking the overall wire length to confirm that the entire wire length, including the active iridium tip portion, has been properly retrieved. The control **13** thereafter determines by communication **342** with computer **22** whether there are additional catheter treatment profiles to be run at **344**. If not, a normal stop at **346** and return to the main menu of computer **22** at **304** occur.

If an additional catheter treatment profile has been programmed, the flow proceeds to block **318** (FIG. **14**) and the turret is repositioned and checked at **320**. Prior to running each active wire treatment profile, the new catheter position is checked by the dummy wire at **326** as previously described.

What is claimed is:

1. Apparatus for moving a radioactive source formed at the end of a delivery wire into and out of a guide tube connected to a patient for the treatment of said patient, said apparatus comprising:

a delivery wire with a source end;

a guide tube;

a program controlled master control unit means responsive to operator interaction for establishing a radioactive source position within said guide tube for the treatment of said patient and for generating treatment command signals specifying said position; and

a remote wire driver unit, said unit comprising:

a motor means to drive said wire;

wire moving circuitry means for moving said source end of said wire into said guide tube in response to wire movement control signals and for generating source movement signals representing the position of said source in said guide tube;

program controlled wire movement control means responsive to said treatment command signals and said source movement signals for generating said wire movement control signals to move said source end of said wire to the position specified in said treatment command signals;

error detection means for sensing erroneous operation in said remote wire driver unit and for generating wire retraction signals in response to such erroneous operation; and

means, independent of said wire movement control means and said wire moving circuitry, for retracting said source end of said wire from said guide tube in response to said wire retraction signals.

2. The apparatus of claim **1** wherein said error detection means includes either means responsive to erroneous operation in said remote wire driver unit for requesting retraction of said source end of said wire by said wire movement circuitry; or

means responsive to a failure of said wire movement circuitry to remove said wire within a predetermined period of time for generating said wire retraction signals.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,092,834

DATED : March 3, 1992

INVENTOR(S) : Anthony J. Bradshaw et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 3, line 58, change "now" to --not--.

Column 4, line 40, change "t" to --to--.

Column 7, line 11, change "drive" to --driver--.

Column 7, line 27, after "36" insert --,-- (comma).

Column 7, line 29, reference numeral "122" should highlighted.

Column 7, line 44, after "contain" insert --an--.

Column 8, line 8, change "note" to --noted--.

Column 8, line 28, after "lines" insert --.-- .

Column 10, line 61, change "drive" to --driver--.

Column 10, line 66, after "treatment" insert --.--

Column 11, line 31, after "number" insert --of--.

Column 12, line 36, after "sensor" insert --and--.

Column 13, line 13, change "92" to --90--.

Column 13, line 40, change "drive" to --driver--.

Column 14, line 3, after "de-energized" insert --,--.

Column 14, line 19, after "shown)" insert --,--.

Column 14, lines 28-29, after "properly" insert --.-- .

Column 14, line 55, after "out" insert --.-- .

Column 15, line 15, change "40" to --90--.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,092,834

DATED : March 3, 1992

INVENTOR(S) : Anthony J. Bradshaw et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 15, line 51, change "than" to --that--.

Column 16, line 11, change "console-to remote" to --console-to-remote--.

Column 17, line 7, change "FIG. 14)" to --(FIG. 15)--.

Signed and Sealed this

Sixteenth Day of November, 1993

Attest:

BRUCE LEHMAN

Attesting Officer

Commissioner of Patents and Trademarks